Salmon Creek Watershed:
Summer 2003 Stream Temperature

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Water Resources Section

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Salmon Creek Watershed: Summer 2003 Stream Temperature

Project Background

The Salmon Creek watershed is comprised of 89 square miles of rural, residential, commercial, forest, and industrial land. Located near the center of Clark County, the watershed extends from the Cascade foothills east of Hockinson, west to Lake River on the Columbia River flood plain. The upper part of the watershed includes large-lot residential parcels and forested areas, and becomes increasingly urbanized as Salmon Creek nears I-5 and Vancouver (Clark County, 2004). Major tributaries to the 26-mile mainstem include Rock, Morgan, Woodin, Curtin, Mill, Tenny, and Cougar Creeks, with some smaller tributaries near Vancouver and many small un-named creeks in the rural areas.

Summertime stream temperatures in the Salmon Creek watershed are known to exceed state water quality and aquatic life use criteria at various locations. Based on stream temperature data collected by Clark Public Utilities (CPU) and Clark County Public Works Water Resources (Water Resources), some stream segments may be included on the 2002-2004 303(d) list of impaired water bodies submitted by Ecology to the U.S. Environmental Protection Agency (USEPA) under the Clean Water Act. The 2002-2004 303(d) list is in draft review at the time of this writing.

Water Resources and CPU have cooperatively performed water quality and hydrologic monitoring in Salmon Creek under an Intergovernmental Agreement (IGA) since September 2002. Based on 1998-2001 data, analyses performed for CPU by Pacific Groundwater Group and HDR Engineering concluded that stream temperatures, though elevated at times, were probably not high enough to adversely impact salmonids. Data collected by Water Resources during 2001 and 2002 suggested that elevated summer stream temperatures may be a larger issue than previously indicated.

During summer 2003, Water Resources and CPU deployed temperature loggers in Salmon Creek and its tributaries as part of ongoing ambient monitoring projects. Water Resources chose to deploy five additional loggers to fill gaps in the network and create a more inclusive dataset to better assess summertime stream temperatures within the Salmon Creek drainage.

Purpose and Scope

The purpose of the 2003 Salmon Creek temperature investigation is three-fold:

1) Determine the extent to which Salmon Creek summer water temperatures meet Washington state aquatic life use criteria and salmonid thermal requirements.
2) Determine whether differences in water temperature between stations are statistically significant.
3) Test for correlations between observed stream temperature and several watershed factors including riparian canopy cover, groundwater influence, and ponds.

This project collected a more extensive single-year stream temperature dataset than any previously compiled for the Salmon Creek watershed. However, the spatial density of logger deployments was not sufficient to assess the occurrence or influence of individual groundwater seeps, isolated areas of cold-water refugia, or impoundments. Rather, the data were assessed for general patterns and indications of the extent of temperature impacts.

Washington Stream Temperature Criterion

Proposed revisions to Washington State stream temperature criteria are under review by the U.S. EPA. EPA is currently withholding approval due to concerns that the revised criteria may not be sufficiently protective of salmonids. Until EPA approves the proposed revisions, the regulatory criterion for Class A waters, including Salmon Creek and its tributaries, will continue to be a maximum temperature of 18 ^{o}C (64 ^{o}F).

Under the proposed revisions, Salmon Creek and its tributaries are protected for the designated uses of: salmon and trout spawning, non-core rearing, and migration; primary contact recreation; domestic, industrial, and agricultural water supply; stock watering; wildlife habitat; harvesting; commerce and navigation; boating; and aesthetic values (WAC-173-201A).

Water temperature under the proposed state criterion will be measured by the 7-day average of the daily maximum temperature (7-DADMax). The 7-DADMax is expressed as the average of daily maximums based on a moving seven-day window. The proposed temperature criterion for streams designated for salmon and trout spawning, non-core rearing, and migration is a maximum 7-DADMax of 17.5 ^{o}C (63.5 ^{o}F).

Salmonid Distribution and Stream Temperature Requirements

Salmonid Distribution in Salmon Creek

Salmon Creek and its tributaries support three anadromous fish species: coho salmon, winter-run steelhead, and coastal cutthroat trout (both anadromous and resident stocks) (HDR, 2002). The Washington Department of Fish and Wildlife (WDFW) Salmon and Steelhead Stock Inventory (SASSI) classifies winter steelhead and coho stocks in Salmon Creek as "depressed" (HDR, 2002). The status of cutthroat trout is unknown, but assumed to be depressed. WDFW recognizes the presence of chum salmon, summer-run steelhead, and fall Chinook salmon as "incidental" (HDR, 2002).

Upstream migration for the three most common species (coho, winter steelhead, cutthroat) ranges from late September to April, with spawning and egg incubation occurring from October to July. Coho and steelhead rear in the stream between 1-2 years before out-migration, while anadromous cutthroat trout may rear up to 4 years (HDR, 2002). Salmonid rearing therefore takes place in the Salmon Creek system year-round.

HDR (2002) reports that over half of the known salmonid spawning in Salmon Creek takes place in the mainstem above the Mill Creek confluence. Morgan Creek and Rock Creek had the highest numbers of spawning redds among the tributaries surveyed, with some redds also observed in Erion and Mill Creeks. Spawning is also thought to occur in Woodin Creek and lower Curtin Creek.

Salmonid Stream Temperature Requirements

Though specific temperature requirements vary between species and from one life stage to another, salmonids as a group tend to be the among the most temperature-sensitive biota in Northwest streams. Past data suggest that elevated stream temperatures in Salmon Creek are most likely to impact salmonids during summer rearing season (HDR, 2002). Rearing temperature requirements are listed in Table 1.

Elevated stream temperatures may cause thermally-induced mortality of cold-water fish in several ways, summarized in Table 2. The exact temperature at which conditions become lethal depends on the temperature to which the fish is acclimated, and on the life-stage of the fish at the time of exposure. The most common cause of thermally induced mortality is the cumulative impact of those conditions grouped in the sub-lethal limit category. Sub-lethal impacts begin to occur at stream temperatures greater than 64°F.

Table 1. Rearing temperatures for Salmon Creek salmonids

Rearing Temperature	Winter Steelhead	Coho Salmon	Cutthroat Trout
Range	up to 23.9°C (75°F)	5°C -17°C (41°F -63°F)	9°C -22°C (48°F -72°F)
Optimal	7.2°C – 14.5°C (45°F – 58°F)	9°C -13°C (48°F -55°F)	12°C -15°C (54°F -59°F)

Adapted from HDR(2002).

Table 2. Modes of Thermally Induced Cold Water Fish Mortality
(Brett, 1952; Bell, 1986, Hokanson et al., 1977)

Modes of Thermally Induced Fish Mortality	Range	Time to Death
Instantaneous Lethal Limit – Denaturing of bodily enzyme systems	> 90°F > 32°C	Instantaneous
Incipient Lethal Limit – Breakdown of physiological regulation of vital bodily processes, namely: respiration and circulation	70°F - 77°F 21°C - 25°C	Hours to Days
Sub-Lethal Limit – Conditions that cause decreased or lack of metabolic energy for feeding, growth or reproductive behavior, encourage increased exposure to pathogens, decreased food supply and increased competition from warm water tolerant species	64°F - 74°F 18°C - 23°C	Weeks to Months

From: Draft Lower Willamette Subbasin TMDL, Oregon Department of Environmental Quality (ODEQ, 2004 draft).

Sources of Heat

Human activities in the Salmon Creek watershed have resulted in significant changes in its vegetation, land use, and hydrologic characteristics. Development, agriculture, and forestry practices have altered stream morphology and hydrology through clearing, wetland drainage, stream channelization, reduced riparian vegetation, and increased impervious surfaces.

Stream temperature is affected by riparian vegetation, stream morphology, hydrology, climate, and geography. Among these, riparian vegetation, morphology, and hydrology are affected by human activities. Non-point sources contributing to elevated summertime stream temperatures include:

- **Near stream vegetation disturbance or removal** reduces stream surface shading via decreased riparian vegetation height, width and/or density, thus increasing the amount of solar radiation reaching the stream surface.
- **Channel modifications and widening** (increased width to depth ratios) increases the stream surface area exposed to energy processes, namely solar radiation. Near-stream disturbance zone widening decreases potential shading effectiveness. Instream ponds…result in the impoundment of water and increased exposure to solar radiation.

(ODEQ, 2004 draft)

Water temperature warms as a result of increased solar radiation loads as more sunlight reaches the stream surface. Highly shaded streams are often cooler due to reduced input of solar energy and a microclimate consisting of cooler air temperatures, higher relative humidity, and lower wind speeds produced by the intact riparian corridor (ODEQ, 2004 draft).

Low summer flows, due to surface water withdrawals, insufficient recharge of shallow groundwater, or drought also contribute to elevated water temperatures through stagnation, increased width/depth ratios, and decreased resistance to thermal inputs. The Salmon Creek Watershed Assessment (PGG, 2002) recognizes surface water withdrawals, streamside vegetation removal, channel modification (widening), and impoundments (ponds) as possible mechanisms by which increased heating of water may occur.

PGG (2002) indicates that the primary source of water in the Salmon Creek watershed during the summer months is shallow groundwater discharge. Data summarizing the current extent of permitted surface water withdrawals in the Salmon Creek watershed are not readily available, and the extent of non-permitted withdrawals is unknown. PGG (2002) notes that CPU groundwater withdrawals come primarily from deeper aquifers and therefore do not have a measurable impact on summer baseflow or stream temperature.

A streamflow "action level" of 12 cfs, measured in the mainstem at the CPU Northcutt gage (east of Interstate 5) was set as part of a 1994 Memorandum of Understanding between Ecology, CPU, and Clark County. It is unknown to what extent this level is protective of salmonids. The Salmon Creek Limiting Factors Analysis (HDR, 2002) concludes that low summer flows do not appear to be limiting to salmonids.

HDR analysis indicates that much of the watershed rates "low" in terms of riparian vegetation. Thirty percent of tributaries and 35% of the mainstem reaches had canopy cover estimated between 0-40%. This equates to 19 miles of mainstem streambed and 34 miles of tributary streambed having less than 40% canopy cover.

HDR documents the existence of 41 online ponds and 28 offline ponds (connected to the channel but not in-line with the channel) covering an estimated 56 acres, concluding that some ponds may be contributing to habitat degradation through increased water temperatures. Figure 1 shows the theoretical stream heating resulting from various sized impoundments given a specified stream flow through the impoundment (ODEQ, 2004).

Detailed stream temperature and flow information for each stream segment containing instream ponds would be necessary to quantify their impact. However, Salmon Creek and its tributaries exhibit elevated stream temperatures in even the uppermost reaches, which suggests anthropogenic (instream ponds, lack of riparian vegetation, water withdrawals, etc.) heat loading. Given the extent of ponds noted by HDR, it is likely that ponds are a significant contributor to elevated stream temperatures.

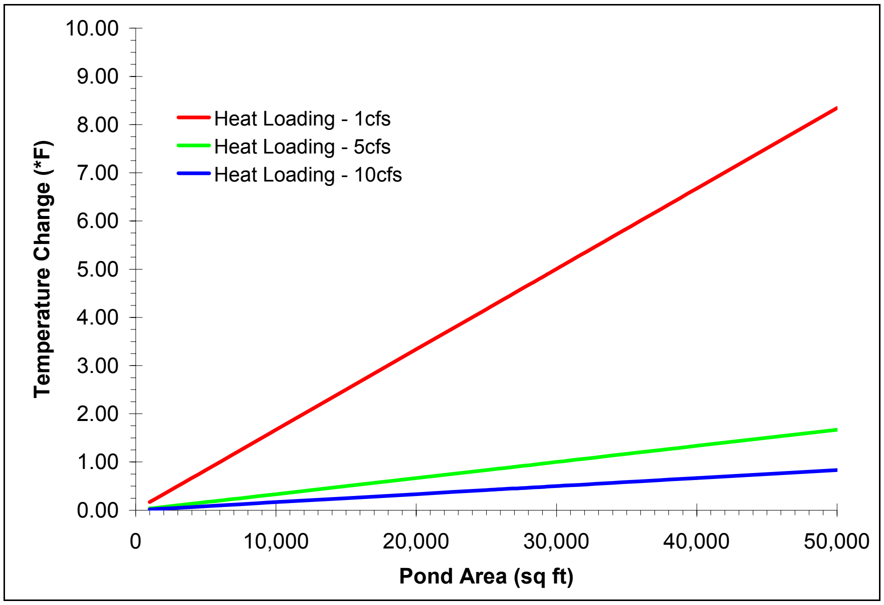

Figure 1. Example of potential heat loading due to ponds (ODEQ, 2004).

Existing Temperature Information

Stream temperature is discussed in several reports, including the 2002 Salmon Creek Limiting Factors Analysis (LFA) (HDR, 2002) and the 2002 Salmon Creek Watershed Assessment (PGG, 2002). This section summarizes existing stream temperature information from the LFA and Watershed Assessment documents.

Salmon Creek LFA

Based on analysis of various temperature data sets collected at up to seven stations during 1998-2001, the LFA finds the following:

- Temperatures during migration, spawning, and emergence were within the range of tolerance for salmon.
- Based on grab sample events during summer "rearing" months, temperatures in excess of 17 ^{o}C were recorded in Woodin Creek, Morgan Creek, and the mainstem at Northcutt (near 2003 station SMN030). Some of these exceedences were substantial (3 – 5 ^{o}C, or 5 - 9 ^{o}F).
- Continuous temperature loggers recorded temperatures >17 ^{o}C at all locations sampled. However, the upper Salmon Creek, Morgan Creek, and Curtin Creek stations had less than 20% of *average daily temperatures* >17 ^{o}C.
- Based on monthly grab sample data and a modified version of the Washington Conservation Commission rating system, June-November rearing temperatures were rated as "good" or "fair" at all stations except in the mainstem at 36th Ave. (2003 station SMN010), which was rated "poor".
- Average daily temperature fluctuation during summer 2000 ranged from 2.3 ^{o}C (4 ^{o}F) in Curtin Creek to 4.3 ^{o}C (7.7 ^{o}F) in Woodin Creek.

HDR also calculated a 7-day moving average temperature for each station based on continuous logger readings. However, the calculations were based on *average* daily temperature rather than *maximum* daily temperature and are not directly comparable with current (maximum of 18 ^{o}C (64 ^{o}F)) or proposed (maximum 7-DADMax of 17.5 ^{o}C (63.5 ^{o}F)) temperature criteria. Based on an examination of the HDR report, actual exceedences of temperature criteria were probably underestimated.

Though some elevated temperatures were recorded, temperature impacts to salmonids were not highlighted as a significant current problem. The LFA states that the "…temperature analysis is somewhat 'slanted' in that the temperature data is typically collected in the middle of the creek, while juvenile fish prefer pools and side channel areas with overhanging vegetation." Additionally, "there may also be sufficient locations of cold-water refugia or areas of groundwater seeps that are currently not documented"(HDR, 2002).

Temperature reduction is not listed as a benefit of any of the recommended actions in the LFA, and no specific actions are recommended to address water quality issues in general. However, continued riparian improvements are recommended among the highest priority actions (Group 1) because riparian buffers aid the recruitment of woody debris that provides needed channel complexity (HDR, 2002).

<u>Salmon Creek Watershed Assessment</u>
The Salmon Creek Watershed Assessment (PGG, 2002) concluded the following with regard to stream temperatures:

- Though not identified as a current problem, increased stream temperature poses the highest risk to fish habitat among the water quality parameters for which state criteria exist (temperature, fecal coliform, turbidity, and dissolved oxygen).
- Temperatures in Salmon Creek and its tributaries "are not yet high enough to be lethal to salmonids".
- At all gaging locations, temperatures generally remain within the "ideal range" from October to May but frequently climb above the ideal range from June to September.
- Data suggest that elevated summer temperatures may limit coho and steelhead rearing unless sufficient cold-water refugia such as pools or areas of groundwater seeps are available.

Methods
Detailed methods for field procedures and data analysis are available from Water Resources.

<u>Station locations</u>
Temperature loggers were deployed at 15 stations on the Salmon Creek mainstem and tributaries. Seven stations characterized reaches of the Salmon Creek mainstem, and eight stations were located on major tributaries near their confluence with Salmon Creek. Figure 2 shows the general locations of the 15 temperature monitoring stations.

Table 3 lists station locations, the agency or consultant collecting temperature data at each station, and the relationship between these stations and other water quality monitoring projects.

<u>Installation/Quality Control</u>
Data loggers underwent and passed pre-and-post deployment accuracy checks against a National Institute of Standards and Technology (NIST) certified thermometer. Two field audits of each logger were performed during the deployment period to verify field accuracy.

Hobo loggers were tested and installed according to procedures outlined in Standard Procedures for Monitoring Activities: Clark County Public Works Water Resources (2003), based on the Timber Fish and Wildlife Monitoring Program method manual (Schuett-Hames, et.al, 1999). Design Analysis loggers were installed as part of permanent stream-gaging equipment using USGS methods.

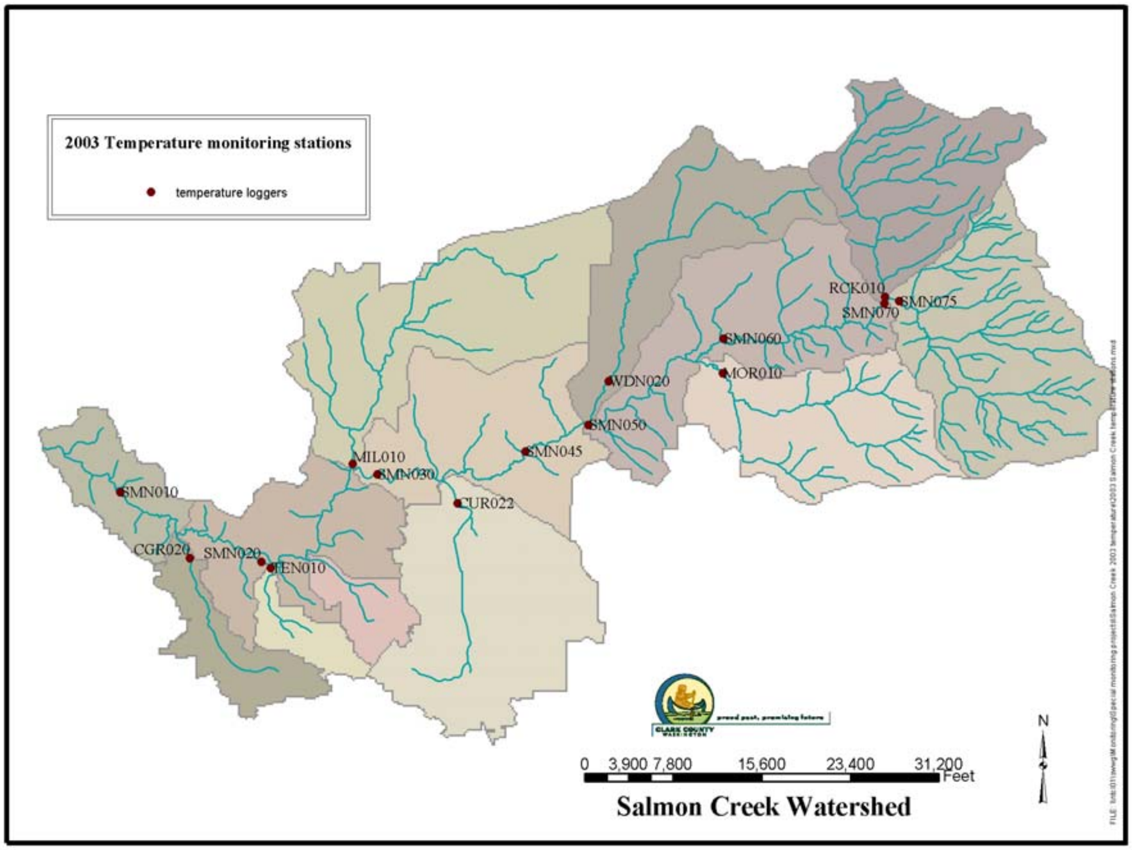

Figure 2. 2003 Salmon Creek watershed temperature monitoring stations.

Table 3. Monitoring locations, logger type, and agency involvement.

Station	Location Description	Station Type	Associated Project*	Logger Deployed by	Logger Type
SMN075	Salmon Cr at Risto Road (217)	mainstem	na	Water Resources	Hobo Temp Pro
RCK010	Rock Cr at S.C. confluence	tributary	na	Water Resources	Hobo Temp Pro
SMN070	Salmon Cr at Risto Road (216)	mainstem	na	CPU	Hobo Optic Stowaway
SMN060	Salmon Cr west of NE 167th Ave	mainstem	na	CPU	Hobo Optic Stowaway
MOR010	Morgan Cr at 167th Ave	tributary	na	Water Resources	Hobo Temp Pro
SMN050	Salmon Cr at Caples Rd	mainstem	SCMP	CPU	Hobo Optic Stowaway
WDN020	Woodin Cr at NE 181st St	tributary	SCMP	CPU	Hobo Optic Stowaway
SMN045	Salmon Cr at NE 156th St	mainstem	CCHMP	River Meas LLC**	Design Analysis H310
CUR022	Curtin Cr dnstrm of NE 139th St	tributary	LISP/SCMP/ CCHMP	River Meas LLC	Design Analysis H310
MIL010	Mill Cr upstrm of S.C. Ave	tributary	LISP/SCMP	Water Resources	Hobo Temp Pro
SMN030	Salmon Cr at NE 47th Ave	mainstem	SCMP	CPU	Hobo Optic Stowaway
TEN010	Tenny Cr upstrm of NW 117th St	tributary	na	Water Resources	Hobo H8
SMN020	Salmon Cr at Klineline footbridge	mainstem	CCHMP	River Meas LLC	Design Analysis H310
CGR020	Cougar Cr upstrm of NW 119th St	tributary	LISP/SCMP	Water Resources	Hobo Temp Pro
SMN010	Salmon Cr at NW 36th Ave	mainstem	SCMP	Water Resources	Hobo Temp Pro

*SCMP: Clark County, Salmon Creek Monitoring Project, Intergovernmental Agreement with Clark Public Utilities
LISP: Clark County, Long-term Index Site Project
CCHMP: Clark County Hydrologic Monitoring Project
**River Meas LLC: River Measurement, LLC, hydrologic consultant to Clark County Water Resources

Data Analysis

Temperature data records were analyzed in Excel using data-conversion macros and the Tempture macro (version 1.1) developed by the Oregon Department of Environmental Quality. This macro calculates maximum daily temperature for the deployment period, 7-DADMax, and days/hours over 64°F, among other metrics.

Statistical comparisons between stations were made using the Friedman test and Tukey's multiple comparison test. These tests make comparisons between each pair of stations based on the *ranks* of the original data on a given date. The statistical comparisons determine which stations consistently rank warmer or colder than others. Both tests interpret the pattern of temperatures among stations on each individual day, requiring data sets of identical length. Statistical tests were performed on data collected from June 27 through September 9 at each station.

Spearman's rho correlation coefficients were calculated between 7-DADMax, Days over 64°F, number of ponds, pond acres, summertime nitrate concentration, and average canopy percentage. A correlation coefficient measures the strength of the association between two variables. Of interest is whether one variable generally increases as the second increases, decreases as the second increases, or whether their patterns of variation are completely unrelated. A significant correlation does not provide evidence for a causal relationship between the two metrics; rather, evidence for causation must come from knowledge of the processes involved (Helsel and Hirsch, 1992).

Limitations to the correlation analysis include: 1) canopy cover was estimated from aerial photos and does not take into account the shade provided by piped stream reaches and/or riparian shrubs and grasses, 2) pond data does not include small ponded areas that are not readily visible on aerial photographs, and 3) nitrate may be a poor surrogate for groundwater influence due to the potential presence of groundwater pollution in developed areas and the influence of hydrogeologic conditions on nitrate formation.

Results

State criteria and aquatic life use

Selected results from the DEQ Tempture v1.1 macro are shown in tabular format in Appendix A.

7-DADMax

Figure 3 is a time-series plot of 7-DADMax temperatures for each station from June 27-September 9, 2003. The legend in Figure 3 lists stations from warmest to coldest, with statistically equal stations shaded the same color (see Differences between stations section).

Temperatures exceeded both the current Washington state criterion (Maximum temperature <64°F (18°C)) and the proposed criterion (7-DADMax temperature <63.5°F) at 12 of the 15 monitored stations during this period. The only three stations meeting the criteria were the Curtin Creek, Tenny Creek, and Cougar Creek tributaries (stations CUR022, TEN010, and CGR020). Peak 7-DADMax temperatures occurred at most stations during mid-late July.

Daily maximum and 7-DADMax temperatures were well into the sub-lethal limit range for salmonids (64°F- 74°F) during most or all of the study period at 12 stations, and extended into the incipient lethal limit range (70°F- 77°F) at seven stations during July.

Figure 4 maps the tributary subwatersheds and mainstem reaches according to the maximum

7-DADMax temperature at each monitoring station. Subwatershed areas are entirely shaded because tributary data loggers represent the cumulative temperature impact of the subwatershed where the tributary discharges to Salmon Creek. Mainstem reaches are depicted

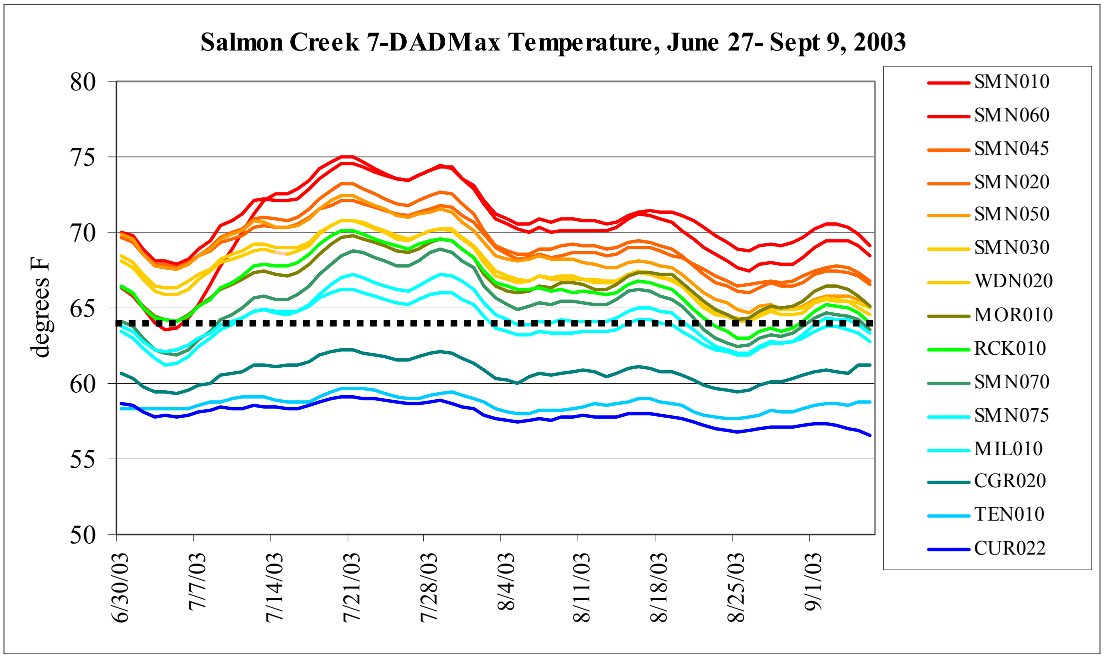

Figure 3. Time-series plot of 7-DADMax temperatures, Salmon Creek, summer 2003. The dotted line at 64° F represents the Washington state stream temperature criterion and the sub-lethal limit above which salmonids are at increased risk of mortality.

only as colored line segments because temperatures at the mainstem loggers incorporate effects from the upstream tributaries as well as the subwatershed immediately surrounding the logger.

The Rock Creek and Woodin Creek subwatersheds, along with the entire mainstem had maximum 7-DADMax over 70°F, followed by the Mill Creek, Morgan Creek and the headwaters subwatershed between 64-70°F.

Time period exceeding 64°F

Compliance with existing (or proposed) state temperature criteria is assessed solely on whether the stream temperature (or maximum 7-DADMax) exceeds the criterion at any time during the year. However, the frequency of exceedences and the length of time spent with stream temperatures exceeding 64°F also give useful indications of the severity of thermal impacts.

Figure 5 shows the number of days on which the maximum stream temperature exceeded 64°F during the deployment period for each logger. Since deployment periods were not identical between stations, Figure 5 should be viewed as a general comparison between stations and an estimate of the number of days with temperatures exceeding 64°F.

At 12 of 15 stations, daily maximum temperature exceeded 64°F on at least 35 days during summer 2003, and at nine stations daily temperatures exceeded 64°F on 55 or more days. The three stations which met the state criterion never exceeded 64°F during the deployment period (Curtin Creek, Tenny Creek, and Cougar Creek).

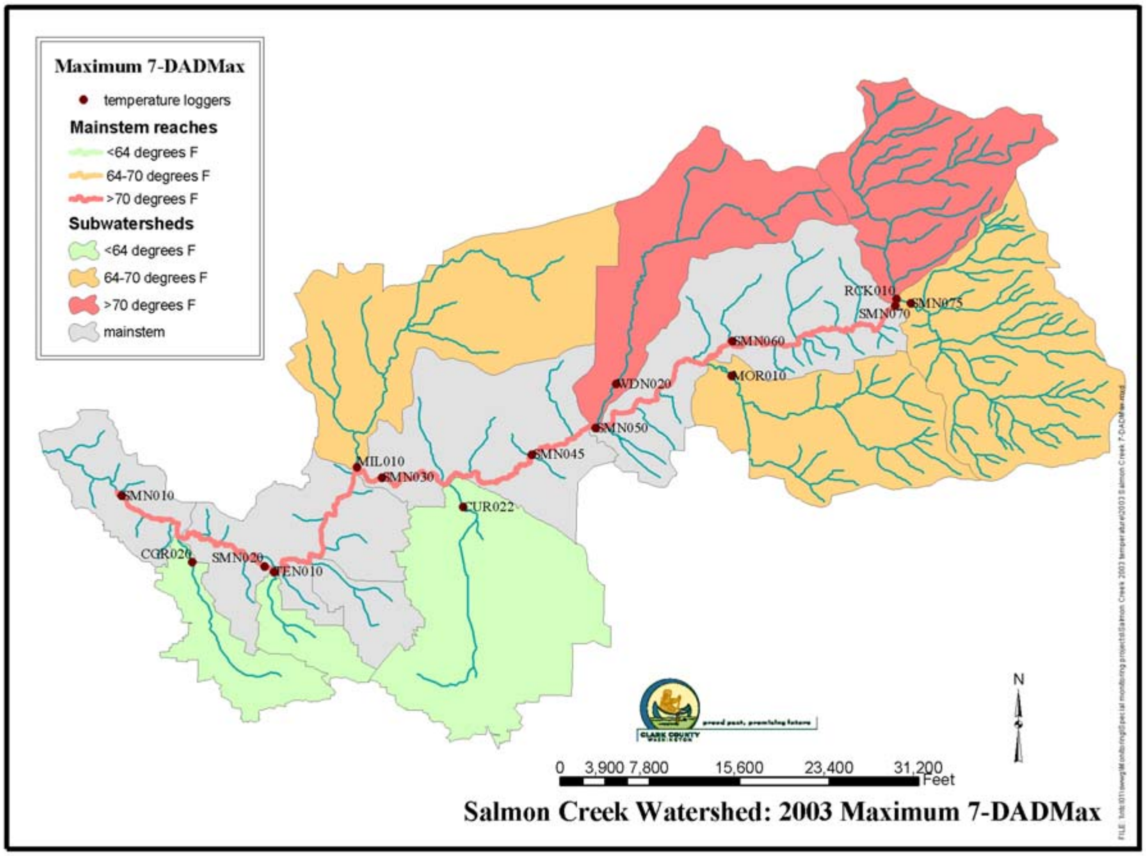

Figure 4. Maximum 7-DADMax temperature for Salmon Creek mainstem and subwatershed stations, June 27-Sept 9, 2003.

A daily maximum temperature over 64°F does not necessarily mean that a station spent a significant amount of time over 64°F on that day; the temperature may have peaked at 64.1° and immediately returned below the criterion an hour later. Table 4 lists the average number of hours spent over 64°F and 70°F on days when the daily maximum stream temperature exceeded these thresholds.

Elevated stream temperatures tended to remain above the thresholds for a considerable amount of time. Among stations where the daily maximum stream temperature exceeded 64°F on a given day, stations SMN075, SMN070, and MIL010 averaged 9 hours/day over 64°F. All other stations averaged between 11 and 20 hours/day over 64°F. On days exceeding 70°F, the average number of hours/day spent above 70°F ranged from 4 hours at SMN070 to 10 hours at SMN010.

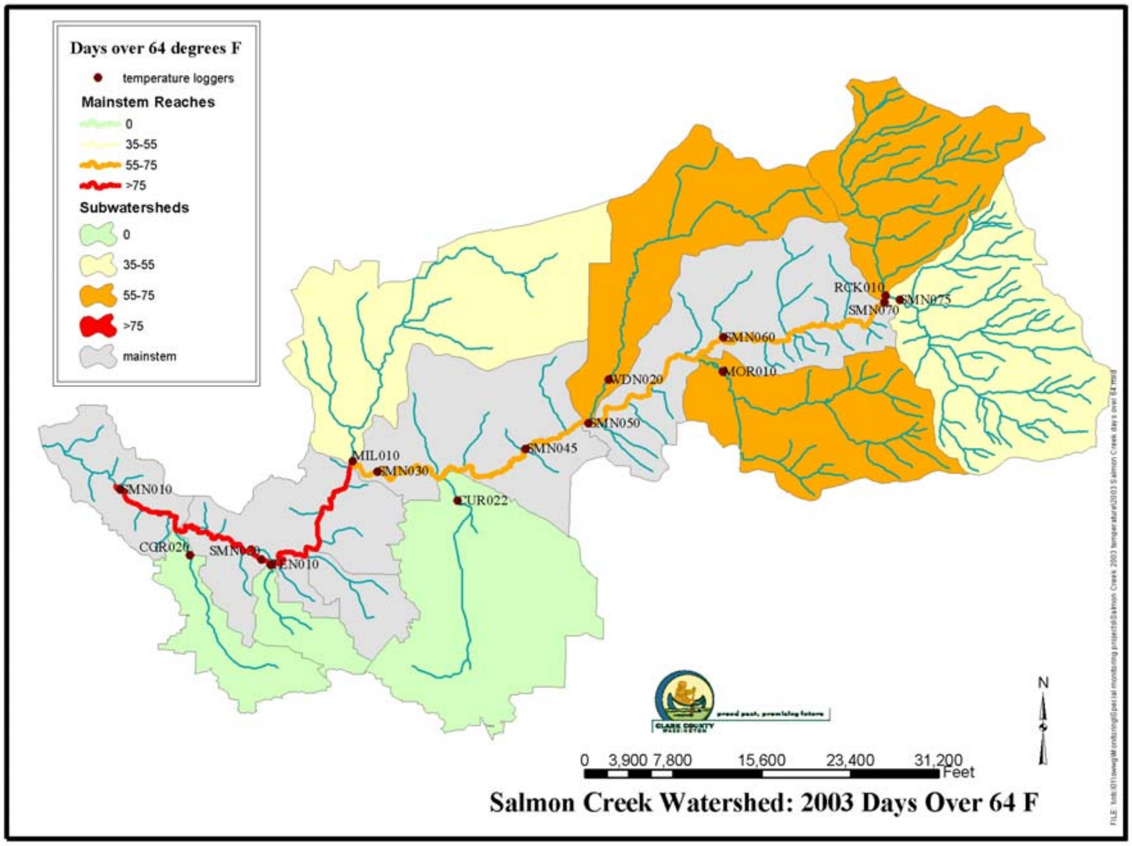

Figure 5. Number of days with daily maximum temperature exceeding 64°F, Salmon Creek watershed, summer 2003.

Table 4. Average number of hours/day spent over 64°F and 70°F, for days with daily maximum temperature exceeding those thresholds.

Station	Hours/day >64°F	Hours/day >70°F	Station	Hours/day >64°F	Hours/day >70°F
SMN075	9	--	CUR022	--	--
RCK010	11	7	SMN030	15	7
SMN070	9	4	MIL010	9	--
SMN060	20	9	TEN010	--	--
MOR010	12	6	CGR020	--	--
SMN050	18	7	SMN020	19	7
WDN020	15	5	SMN010	19	10
SMN045	18	8			

-- no days exceeding this temperature

<u>Differences between stations</u>
Figure 6 is a box-and-whisker plots of the 7-DADMax temperatures for each station from June 27-September 9, 2003. This view highlights the influence of tributary streams (green boxes) and shows the pattern of water temperatures from upstream stations to downstream stations (stations are depicted from upstream to downstream, left to right). The horizontal bar in each box represents the median of the 7-DADMax temperatures for each station.

Except for the mainstem station nearest the headwaters (SMN070), mainstem 7-DADMax temperatures were consistently higher than tributaries. A moderating influence of somewhat cooler tributary water can be seen where Morgan Creek (MOR010) enters Salmon Creek between

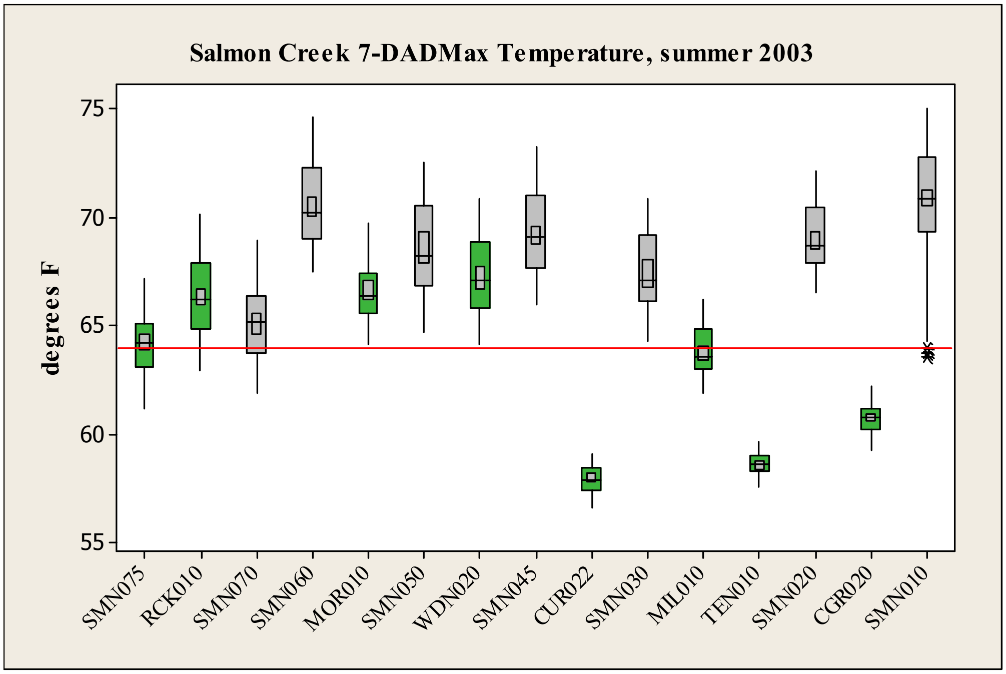

Figure 6. 7-DADMax temperature box-and-whisker plots, June 27- September 9, 2003. Green boxes represent tributary streams. The red line at 64°F indicates the WA state temperature criterion and the sub-lethal limit above which salmonids are at increased risk of mortality.

stations SMN060 and SMN050, and again where Curtin Creek (CUR022) enters Salmon Creek between SMN045 and SMN030.

While mainstem stations below SMN070 were consistently warm, three of the four upper tributaries (RCK010, MOR010, and WDN010) were substantially warmer than the lower four tributaries. A rather dramatic temperature increase was also evident between mainstem stations SMN070 and SMN060, where the median 7-DADMax increases 5°F.

Statistical comparison
Friedman's test indicated with a high degree of confidence ($p < 0.0001$) that the average rank for at least one of the stations was consistently different from the others on a scale of warmest to coldest. Based on this result, the followup Tukey's test was performed to determine which differences between station ranks were statistically significant. Tukey's pairwise comparisons indicated that only three pairs of stations did *not* have a statistically significant difference in rank over the deployment period.

The three pairs of stations having statistically identical ranks were MIL010 vs SMN075, SMN010 vs SMN060, and SMN020 vs SMN030. All other stations were statistically different in terms of their average rank, indicating that individual stations tended to maintain a consistent rank throughout the study period. This pattern also suggests that stream temperatures at all stations were responding to a similar driving factor.

Diurnal variation (ΔT)
The average daily ΔT (change in stream temperature) for each station is shown in Table 6. Average ΔT's during the June 27 – September 9 period ranged from 2.0°F in Tenny Creek (TEN010) to 6.7°F in Rock Creek (RCN010). The colder stations tended to have lower diurnal temperature fluctuation (TEN010, CUR020, CGR020, and MIL010).

Table 6. Average daily ΔT(°F), June 27 – September 9, 2003.

Station	Average daily ΔT(°F)	Station	Average daily ΔT (°F)
SMN075	5.0	CUR022	3.6
RCK010	6.7	SMN030	5.2
SMN070	6.2	MIL010	4.3
SMN060	6.6	TEN010	2.0
MOR010	5.9	CGR020	4.0
SMN050	5.6	SMN020	4.6
WDN020	5.0	SMN010	5.8
SMN045	6.1		

Correlations
For n=15, the critical values for Spearman's rho at the α=0.05 and α=0.01 levels are 0.464 and 0.626, respectively. If the value of Spearman's rho exceeds these values, the null hypothesis that rho = zero is rejected and the correlation is significant at the given confidence level (Sprent, 1989). Regardless of significance, the strength of the correlation increases as the coefficient approaches +1 or -1.

Table 7 shows Spearman's rho correlation coefficients between maximum 7-DADMax temperature, days over 64°F, number of ponds, pond acres, summer nitrate concentration, and average canopy %. The first two metrics are measures of stream temperature, and the final four metrics are watershed factors potentially affecting the observed stream temperatures. Stations were separated into tributary and mainstem groups for this analysis.

Table 7. Spearman's rho correlation coefficients

Tributary Stations	7-DADMax	Days over 64
7-DADMax	1	
Days over 64	0.963	1
# of Ponds	0.331	0.506
Pond acres	0.599	0.651
N03 (May-October)	-0.740	-0.790
Avg Canopy %	0.735	0.753

Mainstem Stations	7-DADMax	Days over 64
7-DADMax	1	
Days over 64	0.881	1
# of Ponds	0.606	0.509
Pond acres	0.587	0.709
N03 (May-October)	-0.212	-0.189
Avg Canopy %	-0.655	-0.775

Tributaries
7-DADMax temperatures were strongly correlated with the number of days over 64°F (0.963). Among factors potentially affecting stream temperature, the pond acres metric was significantly correlated with 7-DADMax at the α=0.05 level (0.599) and with Days over 64°F at the α=0.01 level (0.651).

Summertime nitrate concentration showed a significant negative correlation at the α=0.01 level with both 7-DADMax (-0.740) and Days over 64°F (-0.790). Average canopy % showed a significant positive correlation with both temperature metrics (7-DADMax = 0.735, Days over 64°F = 0.753) at α=0.01.

Mainstem
At the mainstem stations, 7-DADMax was again significantly correlated with Days over 64°F (0.881). Among factors potentially affecting stream temperature, pond acres were significantly correlated with 7-DADMax at α=0.05 (0.587), and with Days over 64°F at α=0.01 (0.709).

Summer nitrate concentration at the mainstem stations showed no significant correlation with 7-DADMax and Days over 64°F. Mainstem stations had a significant negative correlation between average canopy % and both 7-DADMax (-0.655) and Days over 64°F (-0.775) at the α=0.01 level.

Discussion

State criteria and aquatic life use

12 of 15 stations monitored in the Salmon Creek watershed failed to meet current and proposed state water temperature criteria during 2003. Only the stations at Cougar Creek, Tenny Creek, and Curtin Creek met the criteria.

Daily maximum and 7-DADMax temperatures exceeded the salmonid sub-lethal limit (64°F) for extended periods (3-9 weeks) at 12 stations. At the seven warmest stations, daily and 7-DADMax temperatures exceeded the salmonid incipient lethal limit (70°F) for periods lasting from 1 to 6 weeks. On days when the maximum stream temperature exceeded 64°F, stream temperatures remained above 64°F for an average of 9 to 20 hours per day. Temperature impacts were the most substantial and long-lasting in the mainstem, followed by the upper tributaries, especially Rock Creek, Morgan Creek, and Woodin Creek.

At best, stream temperatures in the range observed during summer 2003 exceeded optimal rearing temperatures by a large margin. At worst, stream temperatures may be contributing to increased salmonid mortality and a significant limitation to salmonid rearing.

Previous analysis based on limited data sets identified elevated summertime stream temperatures as a potential risk to salmonids, but concluded that temperatures "are not yet high enough to be lethal to salmonids" (PGG, 2002). Data suggested that elevated summer temperatures may have been limiting coho and steelhead rearing in some areas; however, it was proposed that the possible existence of cold-water refugia in pools or near groundwater seeps may be sufficient to protect salmonids from temperature impacts (PGG, 2002; HDR, 2002).

Results from the 2003 investigation suggest elevated stream temperatures are a larger and more widespread issue than previously concluded. The use of grab sample data and average daily temperatures rather than maximum daily temperatures resulted in an underestimation of temperature impacts in previous studies.

While isolated areas of cold-water refugia may exist in deeper pools, near groundwater seeps, and in the mainstem immediately downstream of cold-water tributaries, the consistency and duration of elevated temperatures, as well as the available stream morphology data, suggest that cold-water refugia are quite limited.

HDR(2002) agrees with Harvester and Willie(1989) in noting that the lack of quality pool habitat and low pool frequency are "limiting in all tributaries and along the mainstem", while 2003 monitoring suggests only a handful of tributary streams contribute sufficiently cool water to create potential areas of thermal refuge within the mainstem.

Nearly all surface water in the Salmon Creek watershed comes from groundwater sources during summer, and this groundwater generally ranges from 50°F to 57°F (Turney, 1990). However, flows tend to be quite low and well mixed during summer; refugia provided by small groundwater inputs may be limited as they are quickly exposed to mixing and thermal processes. In a few tributaries (Curtin, Tenny, and Cougar Creeks), groundwater inputs appear to be sufficient to maintain cold-water conditions despite relatively sparse canopy cover.

Curtin Creek and Mill Creek are the only two salmonid-accessible tributary streams where the available data suggest cold-water conditions regularly exist during summer. The other two coldest tributaries (Cougar Creek and Tenny Creek) are largely inaccessible to anadromous fish due to natural barriers very near their confluences with Salmon Creek.

<u>Differences between stations</u>

Mainstem stations tended to be warmer than tributaries, especially in the lower watershed. In several reaches, tributary inflows appeared to have a moderating influence on mainstem temperatures.

Cooler water from the four lower tributaries helped to slow temperature increases in the lower mainstem, though only Curtin Creek contributed sufficient cold water to produce an overall decrease in mainstem temperature. Average summer flow in Curtin Creek during the study period was 3.5 cfs, considerably higher than Cougar Creek (1.9 cfs) and Mill Creek (1.9 cfs), the only other tributaries with available flow data. Curtin Creek contributed almost 25% of the total Salmon Creek flow measured at the Northcutt gaging station near Interstate 5.

The upper tributaries had elevated stream temperatures in excess of state criteria and only Morgan Creek inflow appears to contribute to a decrease in upper mainstem temperature.

Limited shade and low summer flows likely prevent mainstem temperatures from cooling once they become elevated. Ensuring consistent, cold tributary inflow is critical to moderating these mainstem temperatures.

The most noteworthy difference between mainstem stations occurred in the upper watershed between SMN070 and SMN060, where the median 7-DADMax increased by 5°F. Though no major tributaries enter the mainstem in this area, many small, unnamed tributaries are present. Further investigation of this area is warranted to determine a cause for the temperature increase. Instream ponds or poor shade along the unnamed tributaries could be significant factors. Moderating temperatures in this reach could have a significant benefit for downstream temperatures in the mainstem.

Statistical comparison
Only three pairs of stations were statistically identical in their rank on a scale of warmest to coldest. Observed differences in rank between all other stations were statistically significant.

7-DADMax temperatures fluctuated in a similar pattern at all stations through the summer: e.g. the 5th warmest station tended to remain the 5th warmest station throughout the monitoring period. The consistent pattern among stations indicates that stream temperatures are responding to the same primary driving factor. Based on the observed pattern, seasonal change in air temperature is the primary factor influencing stream temperatures throughout the watershed.

Though all stations followed the same climate-driven temperature *pattern*, there were significant temperature differences between stations. Watershed factors, including stream flow, shade, channel morphology and complexity, and in-stream ponds influence stream temperature to varying degrees at different locations and impact the observed temperature regime. These additional factors determine whether stream temperatures at a particular location will be warmer or colder than at other locations, even though all stations are responding similarly to the primary driver.

Diurnal variation(ΔT)
Average daily temperature fluctuations (ΔT) ranged from 2.0°F to 6.7°F. Daily temperature fluctuation is a normal occurrence and is impacted by a variety of factors, primarily direct solar heating and convective heating/cooling due to changing air temperature. Low streamflows and channel widening may increase these temperature swings because there is a smaller mass of water to heat or cool, and increased width:depth ratios increase the surface area exposed to thermal processes.

Among tributaries, Rock Creek had the greatest average daily fluctuation (6.7°F), followed by Morgan (5.9°F), Woodin (5.0°F), and the headwaters at SMN075 (5.0°F). The colder tributaries tended to have somewhat lower diurnal variation: Curtin (3.6°F), Mill (4.3°F), Cougar (4.0°F) and Tenny (2.0°F). Average ΔT for mainstem stations ranged from 4.6°F to 6.6°F, and was highest at stations SMN070 and SMN060 in the upper watershed.

The difference in daily temperature fluctuation between stations suggests that air temperature is not the sole factor influencing diurnal temperature variation. Again streamflow, shade, and channel morphology likely play a significant role.

<u>Correlations</u>
All four watershed factors correlated significantly with the stream temperature metrics. The strength of the correlations varied somewhat, and no single watershed factor stood out as having much stronger correlation with stream temperature than the others. Due to the limitations in data sets and the complexity of the relationships influencing stream temperature, correlation results must be viewed as a preliminary step.

Viewed in the context of the available data, our current knowledge of the watershed, and the scientific literature, the associations suggested by the correlation analysis indicate that ponds, shade, and groundwater inputs should all be considered carefully when exploring the causes of elevated stream temperature.

Tributary stream temperatures
- increased as pond acres increased
- decreased as nitrate increased, and

- increased as canopy cover increased

Mainstem stream temperatures:
- increased as pond acres increased
- increased as canopy cover decreased, and
- were not significantly correlated with nitrate

The positive correlation between tributary stream temperature metrics and average canopy cover disagrees with established science and casts doubt on the usefulness of attempting to correlate estimated tree canopy cover with stream temperature. HDR (2002) was unsuccessful in using cloud cover as a surrogate for canopy when correlating with stream temperature, and a direct correlation with estimated canopy cover proved no more successful in this study. The analysis may be confounded by the fact that current riparian canopy estimates do not take into account piped stream segments or the shade provided to small streams by dense riparian growth of shrubs and grasses in areas with few trees. Streamflow and the actual density of the canopy also influence the amount of shade-related thermal impact at a given location.

Summary

State criteria and aquatic life use
- 12 of 15 stations failed to meet existing and proposed stream temperature criteria for the state of Washington. Only stations on Curtin, Cougar, and Tenny creeks met the criteria.
- Stream temperatures at most monitoring stations were poor when compared with salmonid thermal requirements.
- Daily maximum and 7-DADMax temperatures exceeded the salmonid sub-lethal limit (64°F) for extended periods (3-9 weeks) at 12 stations. At the seven warmest stations, daily and 7-DADMax temperatures exceeded the salmonid incipient lethal limit (70°F) for periods lasting from 1 to 6 weeks.
- On days with maximum stream temperature over 64°F, stream temperatures remained above 64°F for an average of 9-20 hours per day.
- Temperature impacts were the most significant and long-lasting in the mainstem, followed by the upper tributaries, especially Rock Creek, Morgan Creek, and Woodin Creek.
- Cold water refugia is probably quite limited throughout the Salmon Creek watershed.

Differences between stations
- Tributary streams have a moderating influence on mainstem temperatures; however, many tributaries already exceeded temperature criteria and provided limited benefit.
- A substantial increase in 7-DADMax temperature occurred in the mainstem between SMN070 and SMN060.
- Stream temperature differences between most stations were statistically significant; stations tended to maintain the same rank on a scale of warmest to coldest.
- Seasonal changes in air temperature appear to be the primary driver controlling the pattern of stream temperatures throughout the watershed.
- Watershed factors, including stream flow, shade, ponds, and groundwater contributions determine which streams are warmer or colder relative to the others within the context of seasonal patterns.

Correlations

- Stream temperature metrics were significantly correlated with pond acres, riparian canopy percentage, and stream nitrate concentration.
- Ponds, shade, and groundwater inputs should all be considered carefully when investigating the causes of elevated stream temperature.
- Tributary temperatures tended to increase as pond acres increased, and decrease as nitrate concentration (groundwater) increased.
- Mainstem temperatures tended to increase as pond acres increased, increase as canopy cover decreased, and were not significantly correlated with nitrate concentration.

Conclusions

Elevated stream temperatures in the Salmon Creek watershed are a more significant and widespread issue than previously determined. 12 of 15 stations monitored during summer 2003 failed to meet current and proposed state water temperature criteria. Temperatures regularly exceeded thresholds for detrimental thermal impacts to rearing salmonids. Given the extent and duration of elevated temperature conditions, stream temperature should be considered a limiting factor for salmonid rearing in the Salmon Creek watershed.

Areas of cold-water refugia are likely limited. Maintaining cold tributary temperatures is critical to moderating temperatures in the mainstem. Throughout the watershed, maintaining sufficient summer streamflow is critical to limiting thermal impacts from other watershed factors. Increasing riparian canopy cover, improving cold-water refugia through increased channel complexity (pools), and limiting the influence of ponds will likely contribute to lower stream temperatures.

Care should be taken to preserve existing cool stream temperatures in the Curtin, Cougar, and Tenny Creek tributaries. Temperatures in Mill Creek and the headwaters subwatershed are only moderately elevated and should be preserved and improved. The upper tributaries, particularly Rock and Woodin Creeks, as well as Morgan Creek have substantial thermal impacts.

Temperature impacts in the mainstem are widespread and generally more severe than in the tributaries. Decreasing tributary temperatures and increasing summer streamflow will likely provide the most immediate thermal benefits in the mainstem, while increasing riparian canopy cover along the mainstem will provide benefits in the long-term.

Clean Water Program: Recommended Management Actions

Water Resources activities are part of the Clark County Clean Water Program. The Clean Water Program works to protect and improve water resources through compliance with Clark County's National Pollutant Discharge Elimination System (NPDES) permit under the federal Clean Water Act. Clean Water Program activities include monitoring, education, stormwater capital improvements and stormwater facility maintenance.

The Clean Water Program recognizes several opportunities to assist in moderating stream temperatures in the Salmon Creek watershed:

- The design of stormwater facility retrofits in the Salmon Creek watershed will take into account potential summertime temperature impacts.
- Stormwater planning efforts will continue to encourage the use of infiltration structures whenever possible to assist in shallow groundwater recharge and the enhancement of summer streamflow.
- Results of this study will be shared with agencies and organizations involved with riparian tree planting (CPU, Clark Conservation District, Watershed Stewards).
- Results of this study will be shared with the Washington Department of Ecology and the Washington Department of Fish and Wildlife as baseline information for 303(d) assessment, potential future TMDL development, and fish recovery strategies.
- Outreach efforts (e.g. Small-acreage Program) will be encouraged to point out the thermal impacts of pond development.
- Results of this study will be shared with the Clark County Public Works Transportation Program for consideration in the design of large stormwater facilities and wetland projects.
- Further field investigations may be implemented in subwatersheds with the most apparent temperature issues to better assess the causes of elevated stream temperature.
- The area between stations SMN070 and SMN060 in the upper watershed will be investigated for potential causes of the substantial temperature increase in this reach.

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Appendix A

Site Name	Start Date	Stop date	Seasonal Maximum		Seasonal Max DT		7-Day averages				Days >	Days >
			Date	Value	Date	Value	Date	Maximum	Minimum	D T	64 F	70 F
SMN075	06/12/03	10/13/03	07/30/03	69.6	06/16/03	8.6	07/29/03	67.2	61.0	6.2	43	0
RCK010	06/12/03	10/13/03	07/21/03	72.6	06/28/03	10.2	07/20/03	70.1	61.7	8.4	64	6
SMN070	06/27/03	09/09/03	07/30/03	71.3	07/29/03	9.9	07/29/03	68.9	60.4	8.5	50	5
SMN060	06/27/03	09/09/03	07/21/03	76.8	07/09/03	10.2	07/21/03	74.6	66.3	8.3	74	42
MOR010	06/12/03	10/13/03	07/21/03	72.2	06/16/03	9.8	07/21/03	69.7	63.3	6.5	67	5
SMN050	06/27/03	09/09/03	07/21/03	75.1	06/28/03	9.4	07/20/03	72.5	65.2	7.3	71	20
WDN020	06/27/03	09/09/03	07/21/03	73.4	06/28/03	7.9	07/21/03	70.8	64.5	6.3	67	12
SMN045	06/26/03	10/30/03	07/21/03	75.7	07/28/03	8.8	07/21/03	73.2	65.8	7.4	74	27
CUR022	06/02/03	10/29/03	06/06/03	60.8	06/06/03	6.5	06/05/03	59.6	54.0	5.6	0	0
MIL010	06/07/03	10/13/03	07/21/03	68.2	06/25/03	6.9	07/20/03	66.2	61.2	5.0	36	0
SMN030	06/27/03	09/09/03	07/21/03	73.1	07/09/03	8.1	07/21/03	70.8	64.2	6.6	69	13
TEN010	07/03/03	10/18/03	09/11/03	60.8	10/06/03	4.2	07/21/03	59.7	57.5	2.2	0	0
SMN020	06/02/03	10/26/03	07/21/03	73.9	06/25/03	7.9	07/21/03	72.1	66.8	5.4	89	26
CGR020	06/07/03	10/19/03	07/21/03	63.7	10/06/03	7.4	07/20/03	62.2	57.4	4.8	0	0
SMN010	06/07/03	10/13/03	07/21/03	77.3	07/11/03	11.8	07/20/03	75.0	68.2	6.8	94	50

= mainstem station

Table X. Summary temperature results for Salmon Creek monitoring stations, summer 2003.